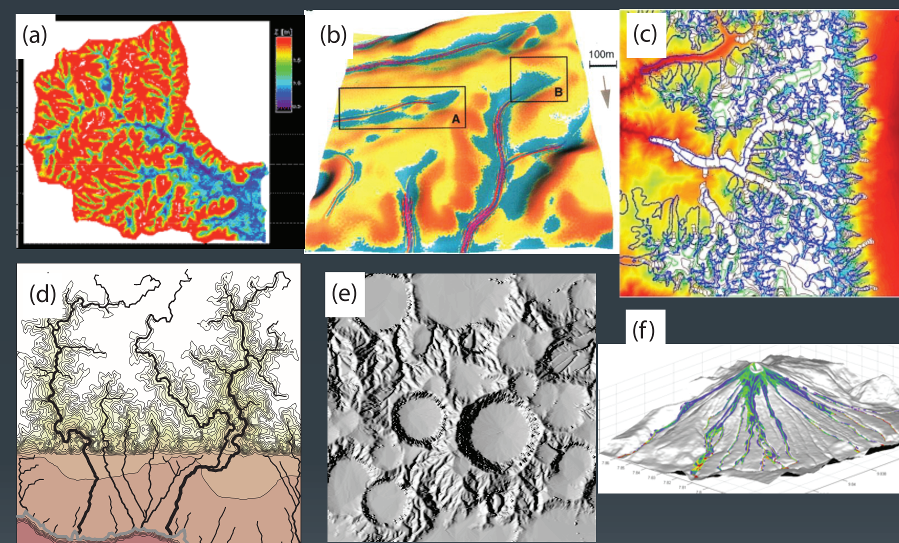
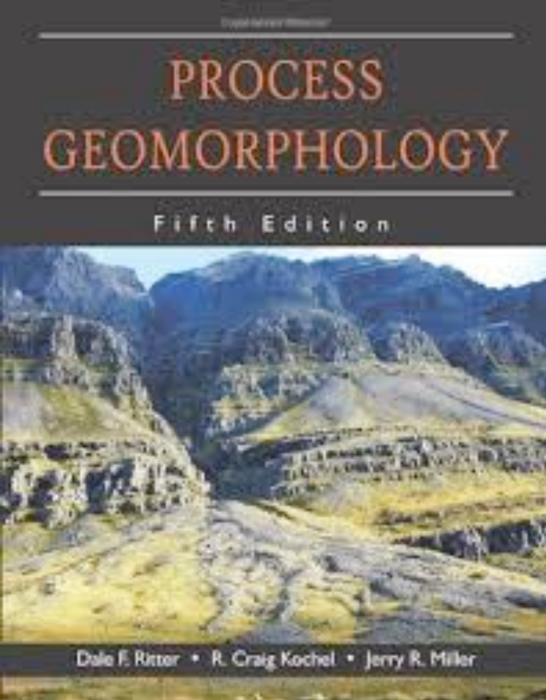
What does “modeling” mean to the surface processes community? Focus on landscape evolution models.

- What is a landscape evolution model?
- How are they used?
- How are they changing?



Nicole M. Gasparini
Tulane University

EarthCube Modeling Workshop for the Geosciences, 22 April 2013



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From Chapter Four: Physical Weathering, Mass Movement, and Slopes:

"We should note that numerous attempts have been made to characterize slope evolution by employing theoretical techniques such as numerical ar [illegible] simulation models (fo [illegible] references, see Carso [illegible] Kirkby 1972; Yo [illegible] 72a; Selby 1982; F [illegible] Dietric [illegible] **ough modeli [illegible] evolution [illegible] is deficient because the a [illegible] of the original slope profile i** [illegible] that is, there is no sure wa [illegible] itial profile. **As a re [illegible] elieve that mo [illegible] e to ou [illegible] nsion of slopes un [illegible] ey are based [illegible] g-term and detailed fie [illegible] measurements (Du [illegible] erley 1980; Selby 1982**).

What is a landscape evolution model (LEM)?

- Generally I'm referring to larger spatial scales, but highly variable – from small watersheds to entire mountain belts.
- Temporal scales vary – could be single events to landscape forming time scales.
- Governed by conservation of mass*
- Geomorphic transport functions (GTF) drive erosion, sediment transport, and deposition across the landscape – on hillslopes, in river channels, in glacial valleys, from a meteorite – and are key to a LEM.
  - GTFs are the focus of much of the geomorphic community.
  - GTFs are derived and tested from field, physical laboratory and numerical research.
- Weathering often not included.

Some thoughts based on

State of Science

Modelling landscape evolution

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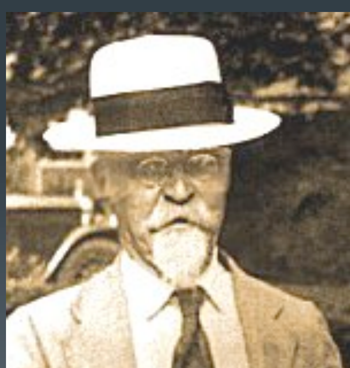
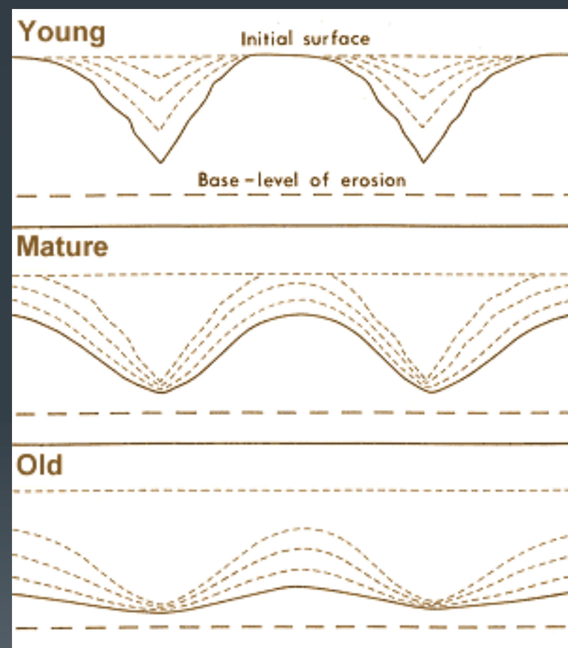
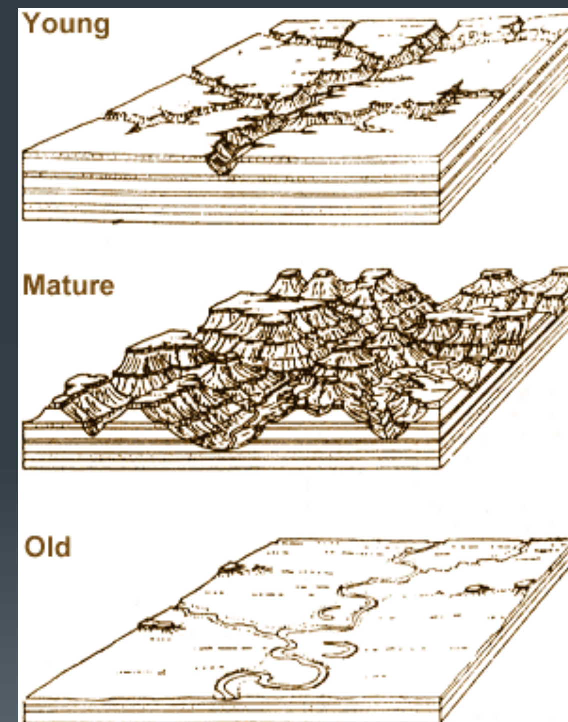
EARTH SURFACE PROCESSES AND LANDFORMS
Earth Surf. Process. Landforms **35**, 28–50 (2010)

Published online in Wiley InterScience
(www.interscience.wiley.com) DOI: 10.1002/esp.1952

William Morris Davis
(c. 1884)
"Cycles of Erosion"







http://www.sgp.org.pl/gw/wmd/wmdfig.html

http://bss.sfsu.edu/jdavis/geog810/othermaterials/wmdavisDiscussion.html

Other reviews by Coulthard, 2001, Hydrologic Processes & Willgoose, 2005 Annu. Rev. Earth Planet. Sci.

No lack of LEMs.
From Tucker and Hancock (2010)

Table I. Partial list of numerical landscape evolution models published between 1991 and 2005

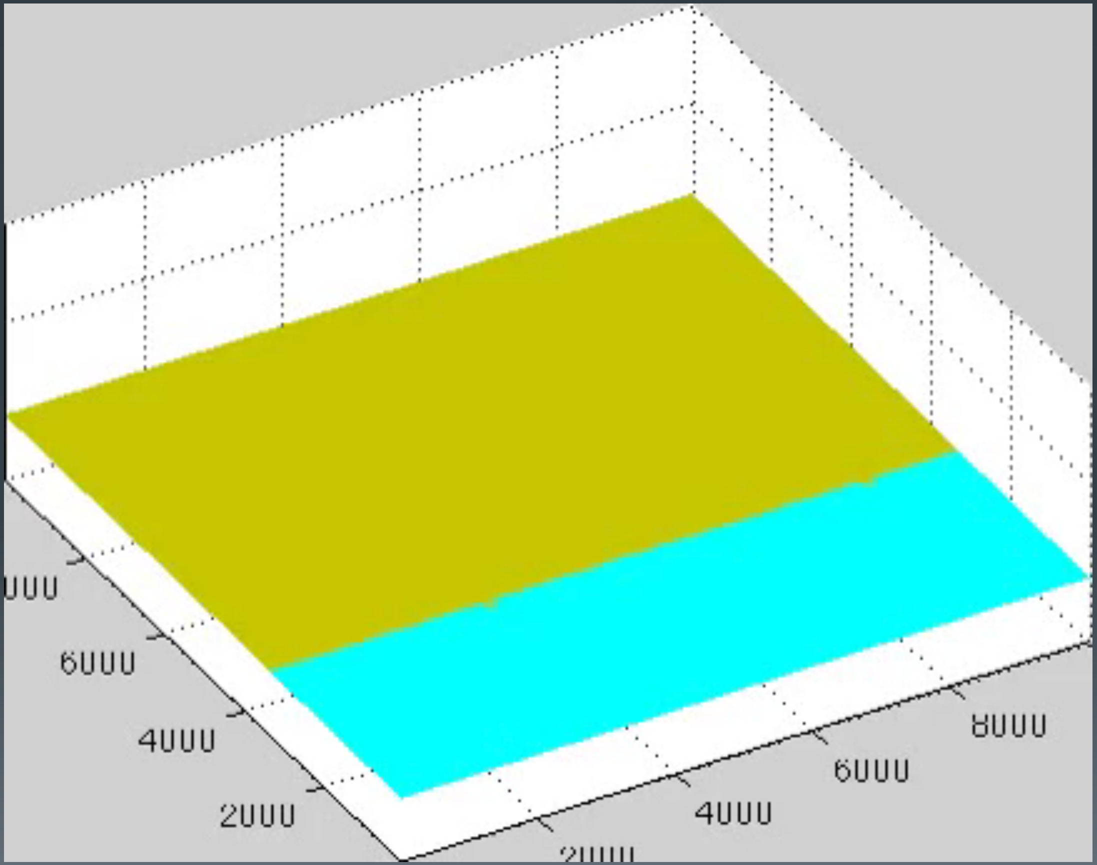
Model	Example reference [a]	Notes
SIBERIA	Willgoose *et al.* (1991)	Transport-limited; introduces channel activator function
DRAINAL	Beaumont *et al.* (1992)	Fluvial transport based on 'undercapacity' concept
GILBERT	Chase (1992)	Cellular automaton
DELIM	Howard (1994)	Detachment-limited
GOLEM	Tucker and Slingerland (1994)	Introduces algorithms for regolith generation and landsliding
CASCADE	Braun and Sambridge (1997)	Introduces irregular discretization method
CAESAR	Coulthard *et al.* (1997)	Cellular automaton algorithm for 2D flow field
ZSCAPE	Densmore *et al.* (1998)	Introduces stochastic bedrock landsliding algorithm
CHILD	Tucker and Bras (2000)	Introduces stochastic treatment of rainfall and runoff
€ROS	Crave and Davy (2001)	Modified precipiton algorithm
APERO/CIDRE	Carretier and Lucazeau (2005)	Single or multiple flow directions

[a] First reference in mainstream literature.

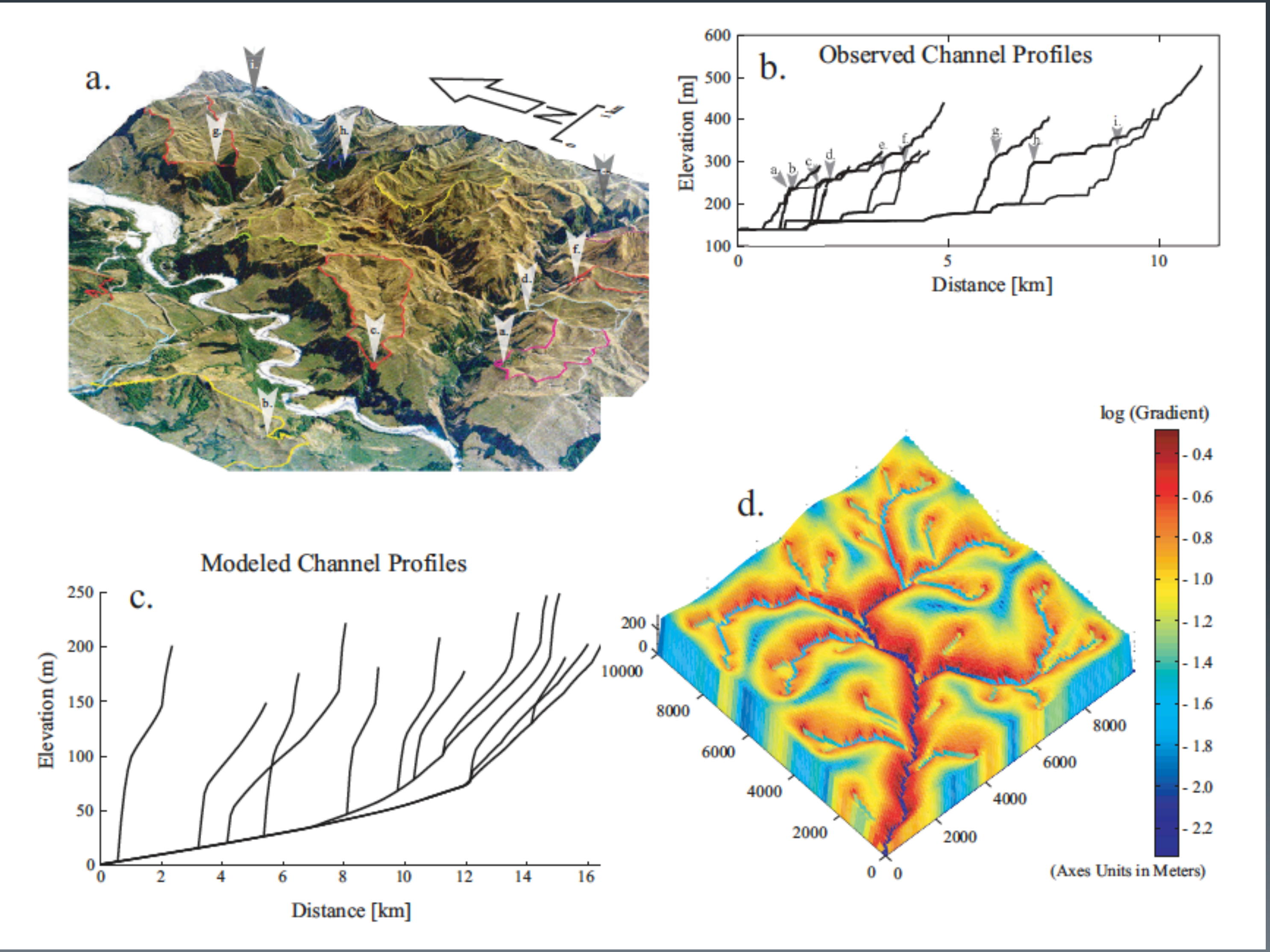
- Ahnert (1976) – usually the first credited 2-D numerical LEM
- Others include LAME (George Hilley), MARSSIM (Alan Howard), SIGNUM (Domenico Capolongo), Gc2d (Mark Kessler), SIMWE (Helena Mitasova), WILSIM (Wei Luo), DAC (Sean Willet), …
- See http://csdms.colorado.edu/wiki/Terrestrial_models for many of the open source LEMs.

CHILD model fault block evolution

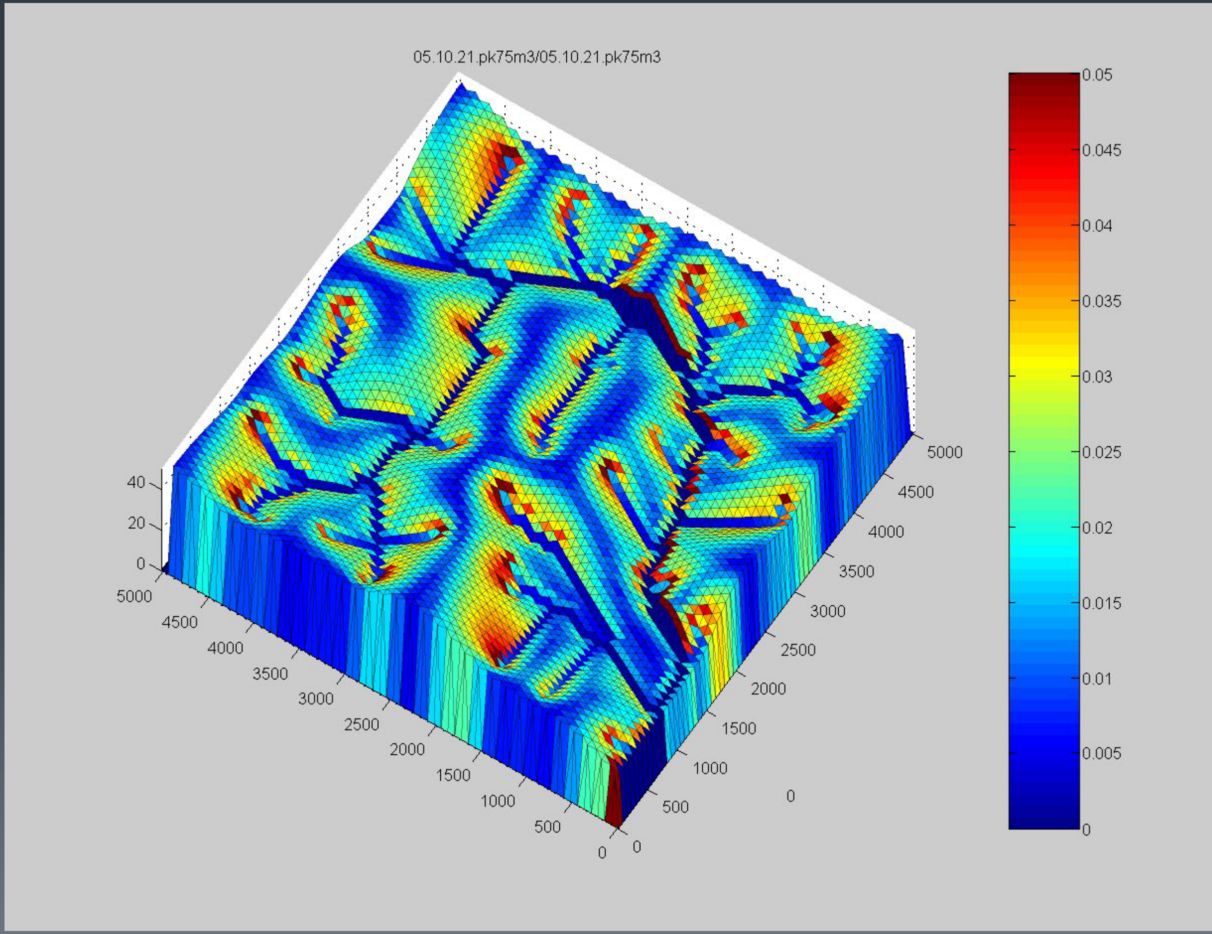
http://csdms.colorado.edu/wiki/Movie:River_incision_dominated_by_fault_block



Crosby et al. (2007) used the CHILD model to understand the Waipaoa watershed evolution.



Movie from Crosby et al. (2007). Understanding the Waipaoa without modeling it exactly.

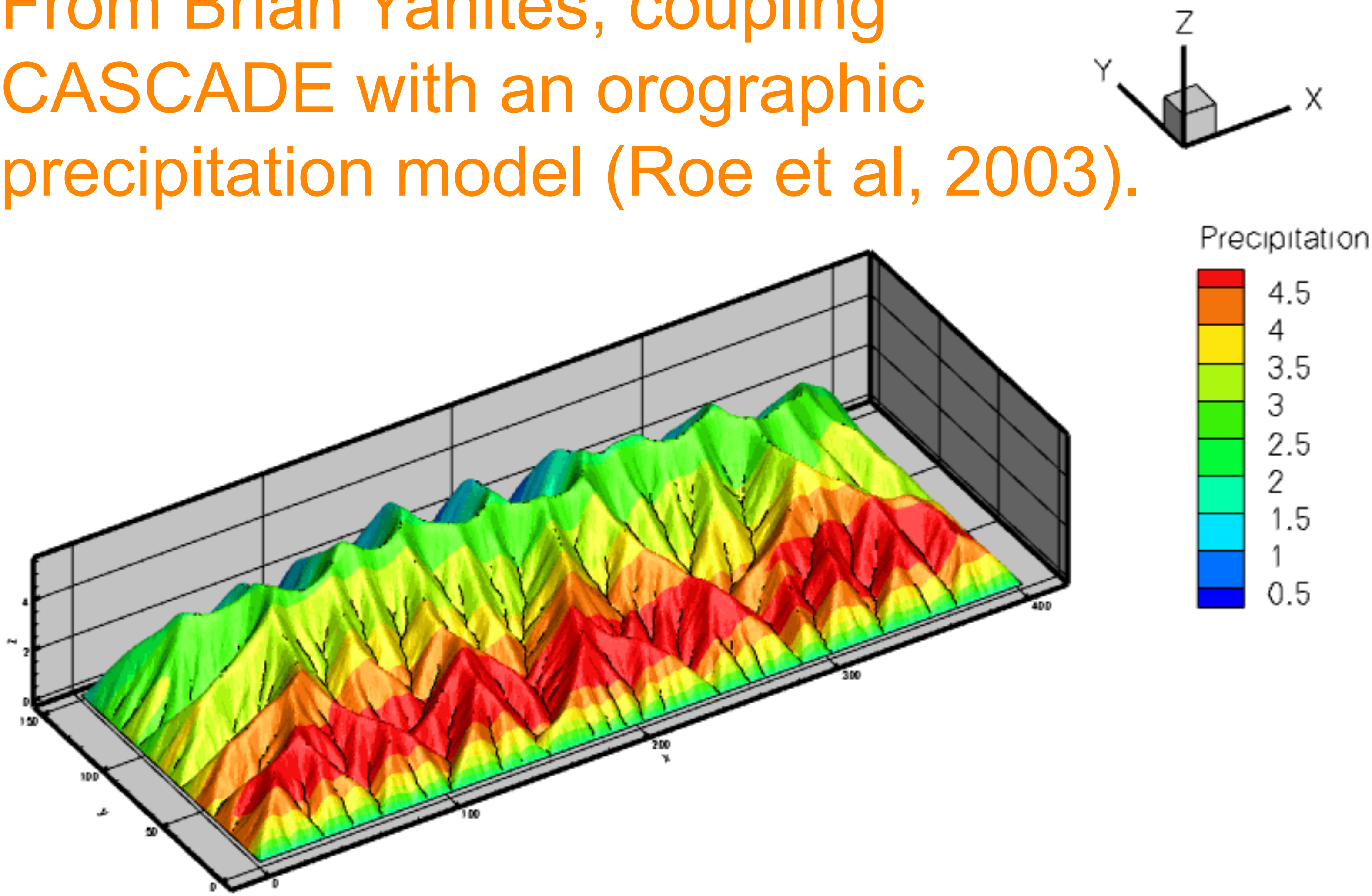


Pedersen and Egholm (2013).
Model of glacial evolution and glacial erosion.

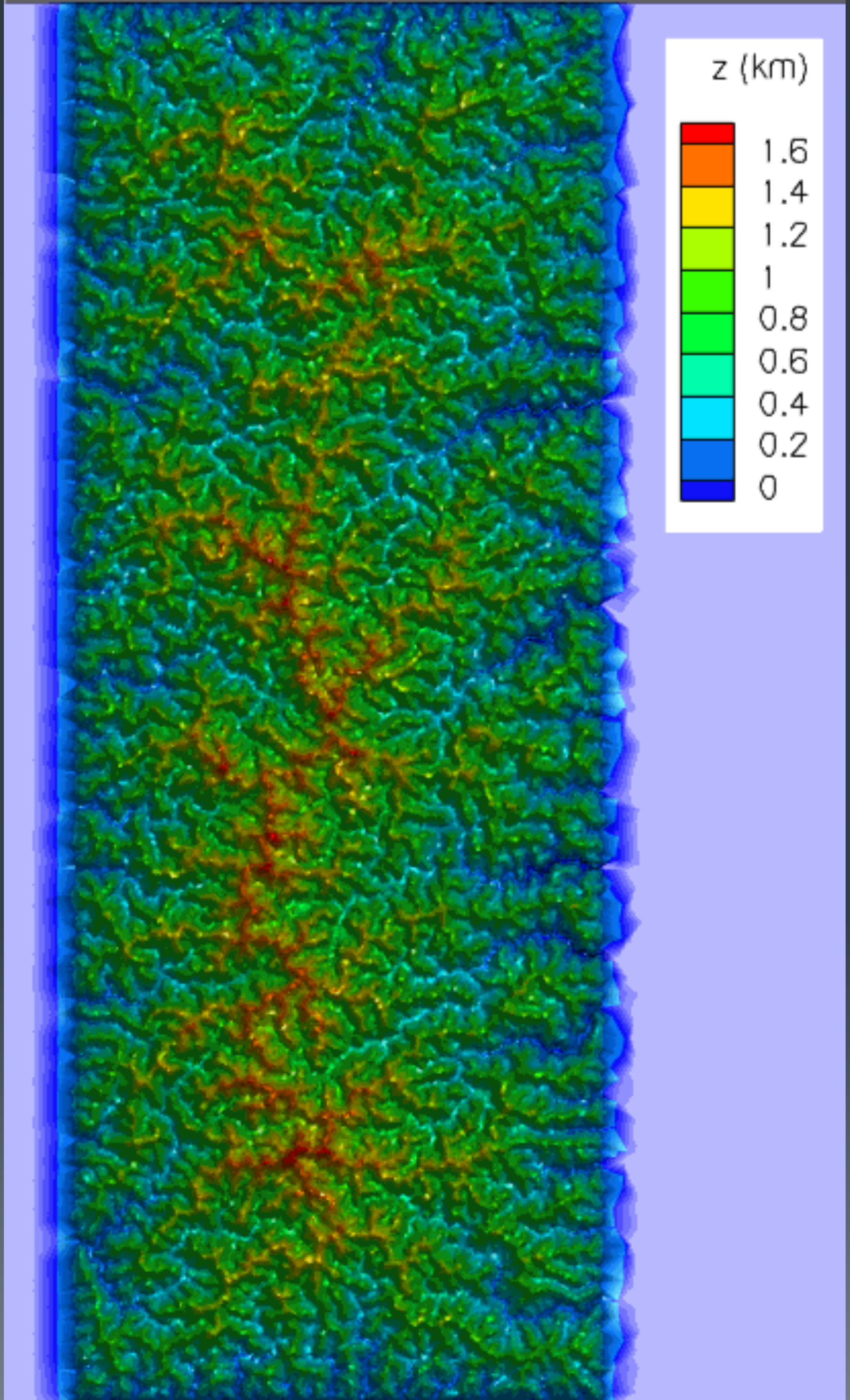
Boundary conditions are important. In a LEM, that means climate and tectonics.

- Any GTF that includes the surface gradient as a variable (all of them?) will be affected by tectonics.
- Simple uplift and lateral motion may be modeled within the LEM.
- More sophisticated approaches may link a tectonic model with a LEM.
- Similarly, rainfall and temperature are important drivers of many surface processes and are included in GTFs.
- LEMs may include spatially and temporally variable rainfall.
- Coupling between atmospheric and surface process models is also ongoing.

From Brian Yanites, coupling CASCADE with an orographic precipitation model (Roe et al, 2003).



Yanites and Ehlers (2012), linking ICE-Cascade with Roe et al. (2003) orographic precipitation model to quantify the effect of the “glacial buzzsaw”.



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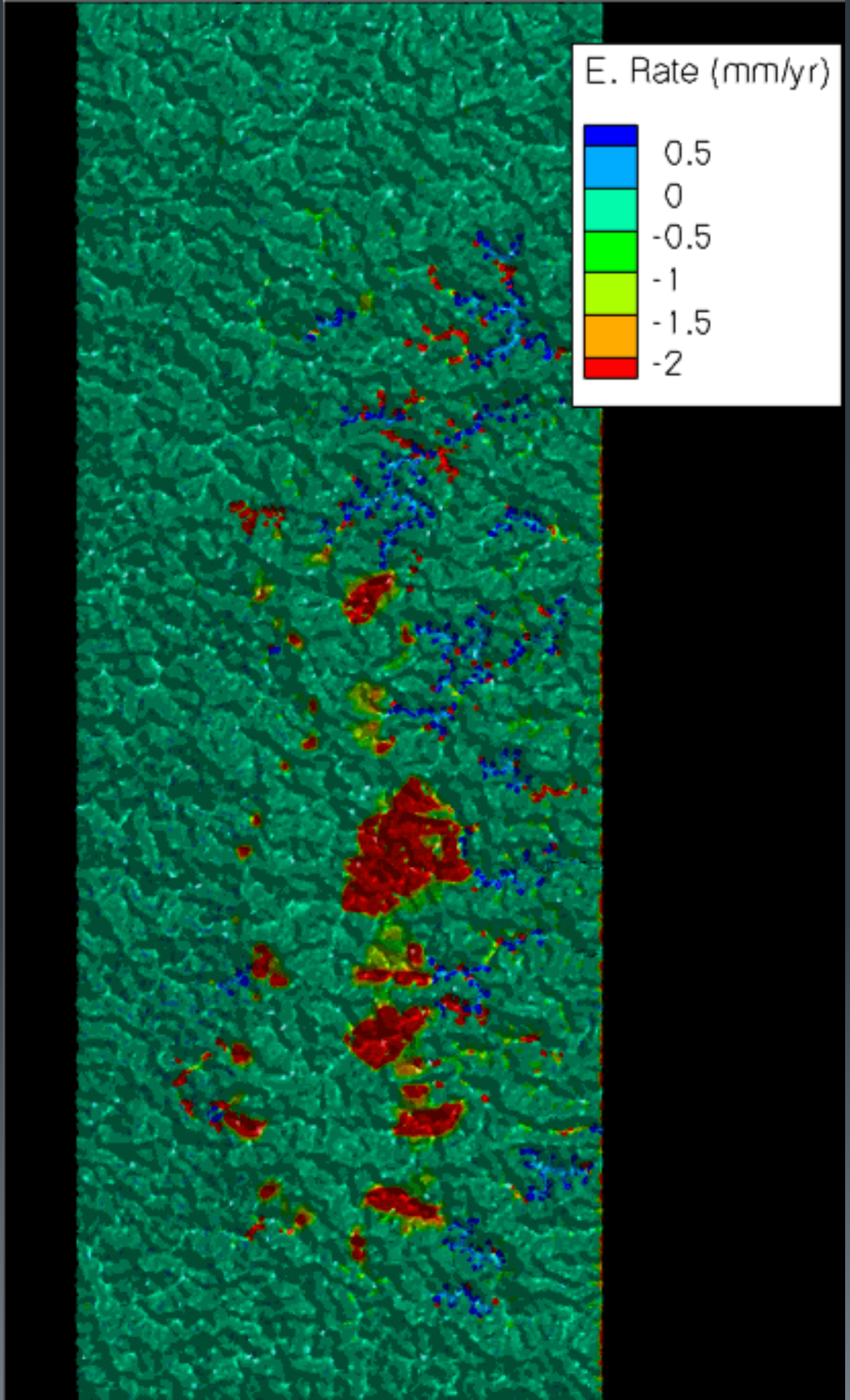
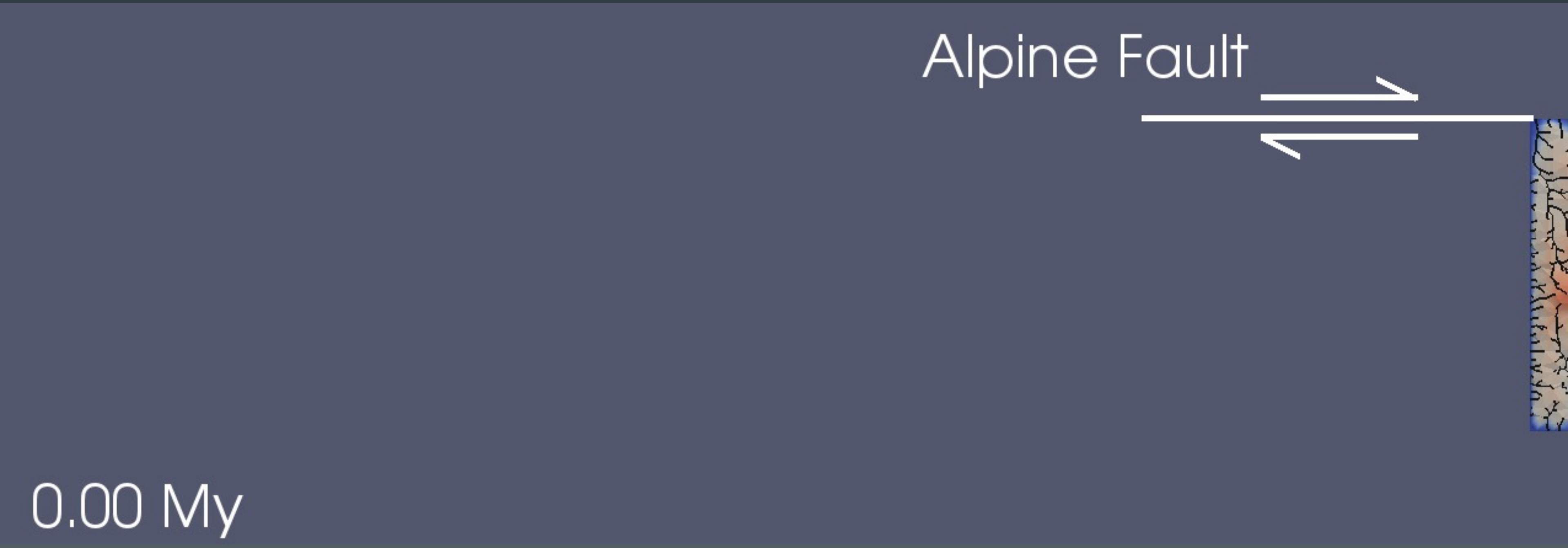
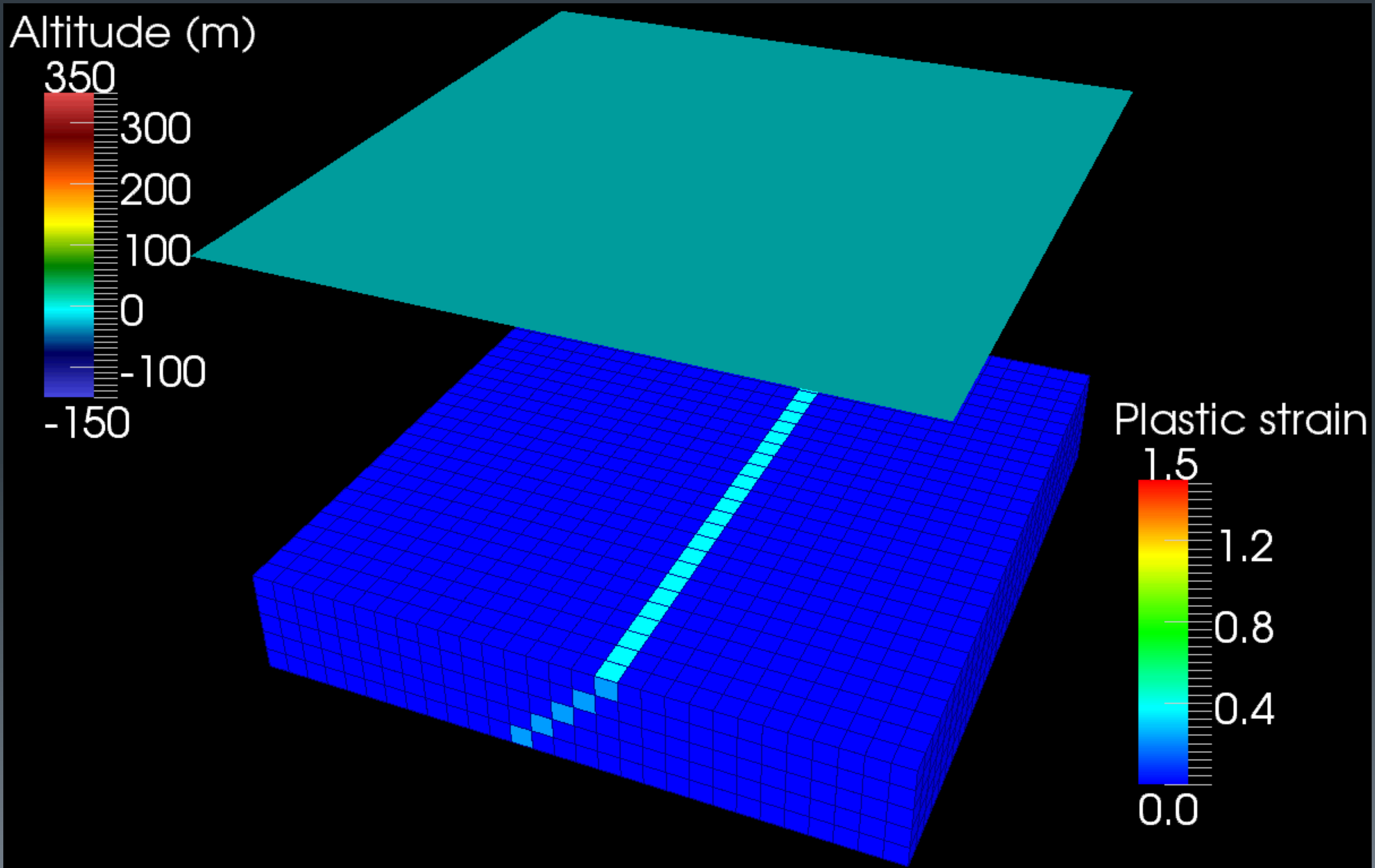


Castelltort et al. (2012) use DAC to explore how climate and shear patterns affect drainage rearrangement in New Zealand.

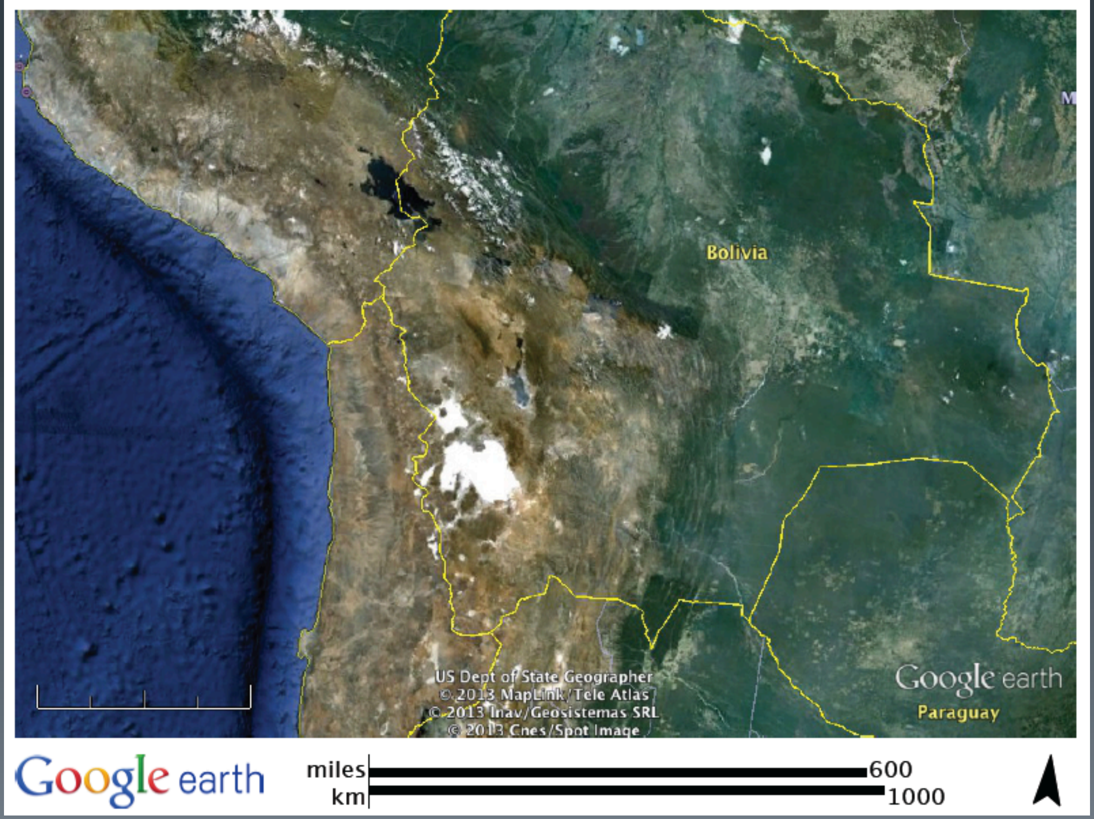


Coupling CHILD with the SNAC tectonic model. Eunseo Choi. http://www.geodynamics.org/cig/software/snac



Where are we going?

- As we continue to couple models, theoretical studies will be needed.
- At the same time, as more data become available to describe the evolution of real landscapes, models can step in to fill gaps in what we don't know about these landscapes.



Where are we going?

- What data inform landscape evolution studies?
  - High resolution DEMs
  - Incision and erosion rates
  - Exhumation history (thermochronology)
  - Current climate; Paleoclimate
  - Seismic data
  - …
- What don't we know? The known unknowns.
  - Process details or dominant processes.
  - Uplift history.
  - Climate history.

e.g.

UNAVCO

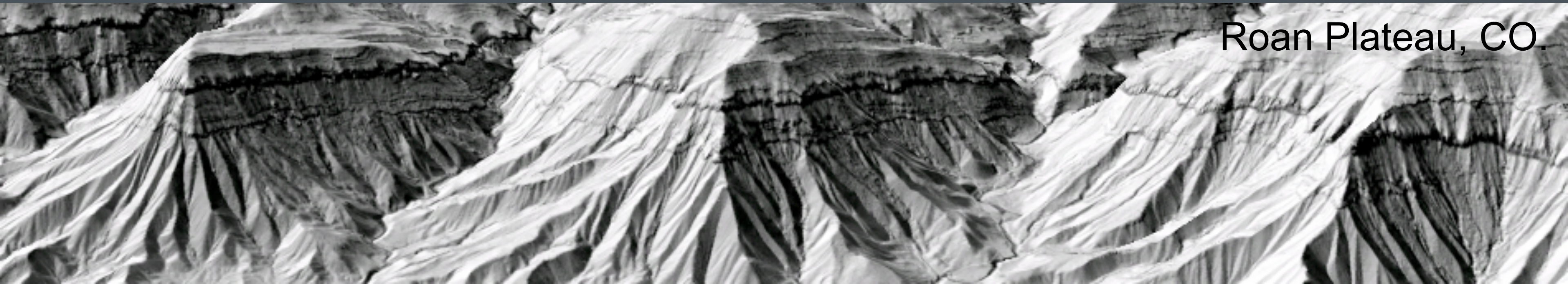
SHUTTLE RADAR TOPOGRAPHY MISSION SRTM NIMA NASA JPL DLR ASI

TROPICAL RAINFALL MEASURING MISSION TRMM

CRONUS-EARTH

NCALM The National Center for Airborne Laser Mapping University of Houston • University of California, Berkeley

OpenTopography

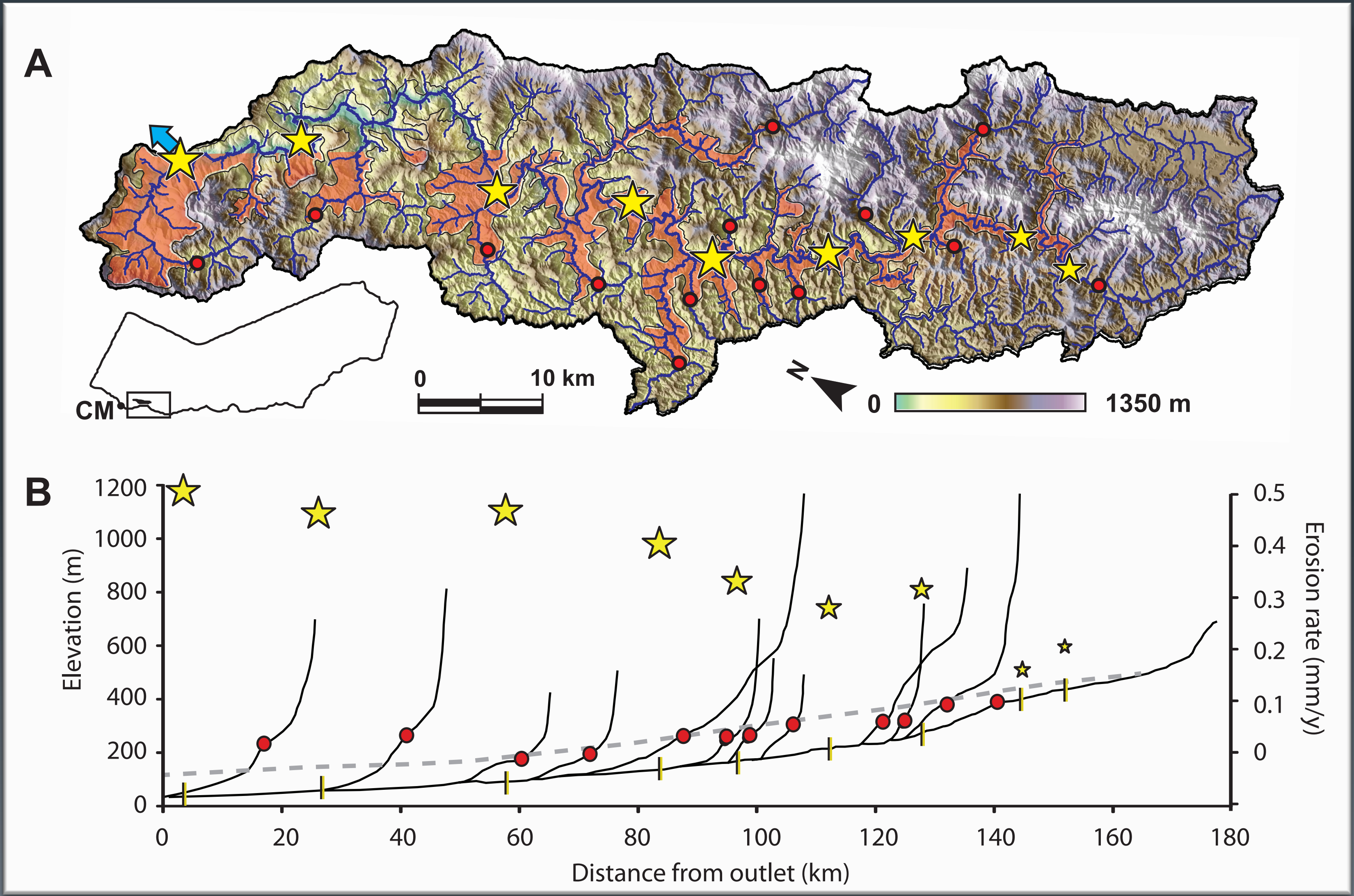


Roan Plateau, CO.

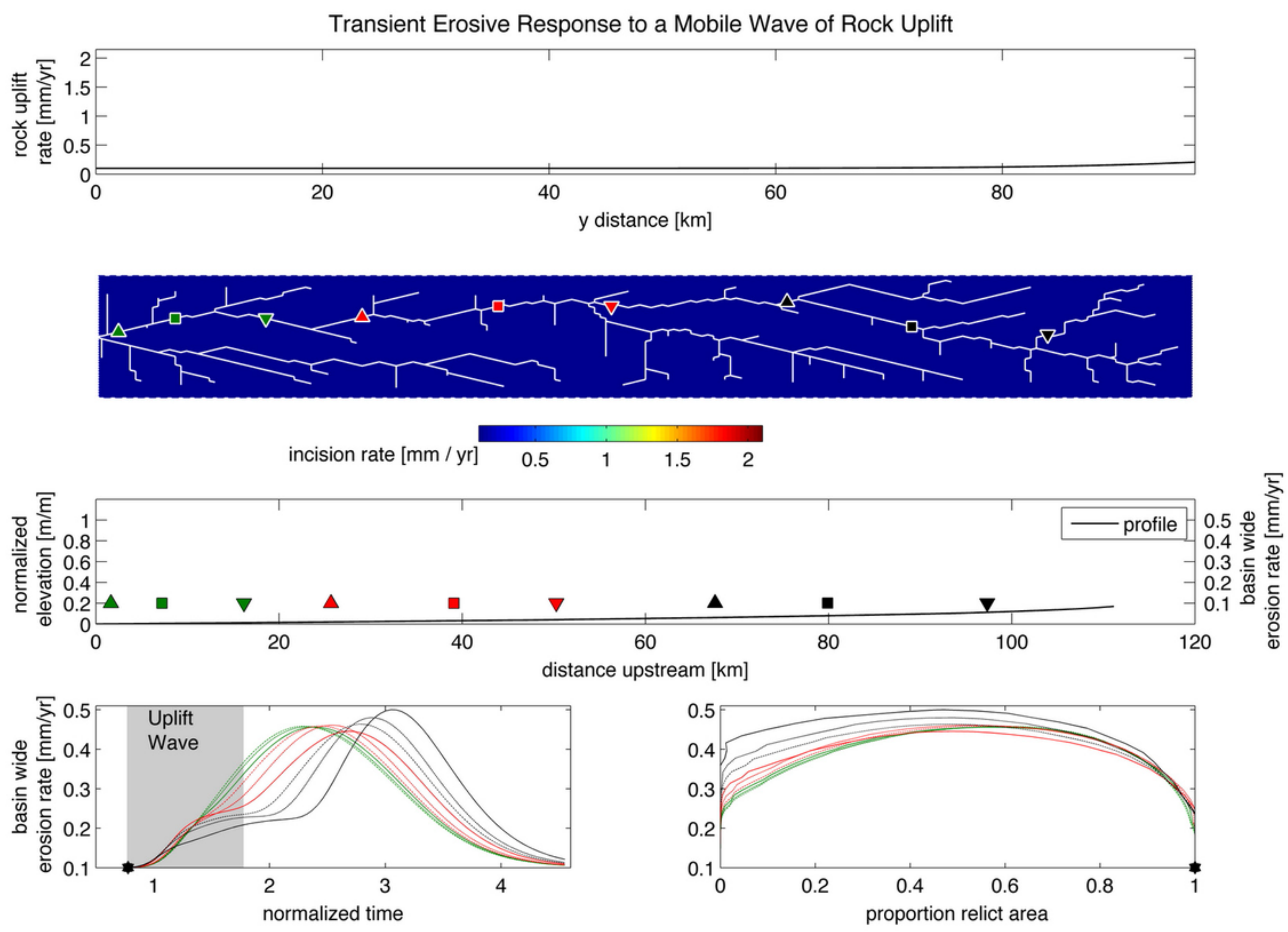
Challenges and Limitations

- Usability of models and model sharing.
  - Lack of documentation. Non-open model codes and platforms.
  - CSDMS is helping. Landlab model.
- Coupling of models requires more computing power.
  - More processes require more processing.
  - Challenges with parallelizing LEMs.
- Numerical modelers need access to “real” data.
  - Data need documentation.
- Non-modelers need access to model data.
  - Data need documentation.
- Communication and collaboration.
- Learn the tricks of your colleague’s trade.

South Fork Eel River: My story of collaboration and linking a model with “real” data. Costarring Jane Willenbring and Ben Crosby.



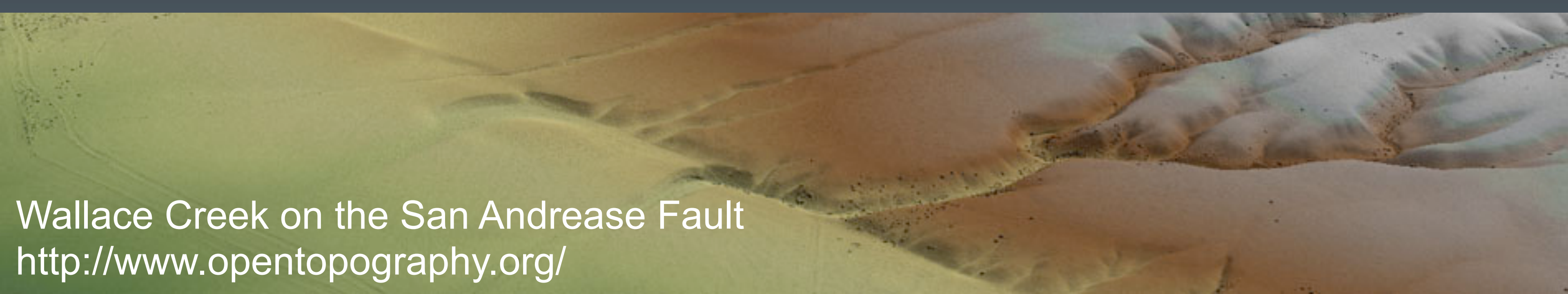
Modeling *motivated* by the South Fork Eel River. Informed by field mapping, DEM analysis, and erosion rate patterns from cosmogenic radionuclide dating.



What’s next for landscape evolution models?

- Good: Lots of data are available.
  - More opportunities to test, constrain, and learn from our models.
- Bad: Lots of data are available.
  - Models are accountable.

- Open questions:
  - What can we ask our models to do?
  - Are more processes better?
  - Over what temporal and spatial scales can we reasonably apply our models?



Wallace Creek on the San Andrease Fault
http://www.opentopography.org/